Study on an Automation System of NC Sawing Machine

Miaofen Zhu, Guojin Chen*, Chang Chen, Youping Gong, Huipeng Chen, Chuan Li

Hangzhou Dianzi University, Hangzhou, 310018，China, chenguojin@163.com

***Abstract* — In the sawing process, because of the changes of the material properties and the section shapes, the cutting load has a fluctuation, which affects the cutting precision and the surface quality. At the same time, in different conditions, the characteristic parameters of the cutting load are very different, which makes the dynamic characteristics of the drive system of the CNC sawing machine be not satisfactory, so that the driving system will decrease the efficiency and increase the energy consumption. In this paper, a method of adaptive frequency conversion control with load characteristic identification is proposed, and the corresponding control system is designed. The simulation and experiment show that the speed fluctuation, the load change, and the adjustment time of the control system are very short. The adaptive capability of the driving system of the CNC sawing machine for the load and other parameters is strong. On this basis, the numerical control system based on the real-time detection, the error compensation and the auxiliary machinery intelligent control is developed, which improves the cutting accuracy and production efficiency of the CNC sawing machine.**

Keywords - Automation system; Sawing machine; Adaptive control; Load characteristic identification; Error compensation

I. INTRODUCTION

The sawing process from blanking to fining gradually has higher requirements to the design and manufacturing level of cutting equipment. The cutting equipment is also gradually to the high-end product development. The development trend of high-end cutting equipment mainly shows in the following aspects in the world.

(1) The cutting precision. The variable frequency motor drives the ball screw, and the precise and accurate positioning method is used. Combined with the advanced hydraulic system, the computer processes and monitors the condition of the cutting equipment on-line. The cutting speed, feeding rate, saw blade tension, workpiece compression and cutting force can be set to optimize the matching parameters. Thereby the processing precision of cutting device can be improved. When cutting thick materials, the height error of each 100mm cutting is only 0.1mm.

(2) The cutting load feedback control. One of the key technologies in metal cutting is to control the sawing equipment. Germany BEHRINGER GmbH is a good solution to this problem. The sawing equipment can realize the constant cutting force control to ensure the sawing rate for irregular profiles (sawing area/min) is constant, and the machining accuracy is higher. Amada Corporation uses the pulse control technology to increase the stability of the saw blade and to reduce the vibration. That not only improves the cutting precision, but also the life of the saw blade.

(3) The higher efficiency in sawing process. In the past, processing thick materials and hard metal materials was always the bottleneck of the production line. It becomes the concern focus of the technical field of sawing equipment for many years. Germany BEHRINGER GmbH has successfully solved this problem. Its cutting rate for stainless steel is $48cm^2/min$.

(4) The enlargement in cutting capacity. At present, the China's largest sawing devices can cut the pipes of 3m diameter and the hollow materials. The Germany BEHRINGER's horizontal cutting devices can saw the square solid materials of 2.5m×2.0m. The giant vertical sawing equipment can saw the plates and rods of up to 10m.

(5) The network and automation of the sawing control. The cutting process of large workpieces usually lasts for hours. In order to realize the production of multiple machines with one man, the cutting equipments are connected with network. The network production can make the cutting process be linked with each other. It is advantageous for the enterprise to achieve efficient management of each link and to realize the automation of the sawing process.

(6) The remote diagnosis and maintenance of the sawing process. The transnational and trans-regional diagnosis and maintenance can be realized through the network. For example, Germany BEHRINGER CNC cutting equipments can be processed with the Technology Center online, and the technical experts diagnose and maintain the cutting equipments remotely.

In order to improve the control level, the sawing precision and the cutting efficiency, the control model on the sawing devices must be studied, and the intelligent embedded CNC system should be developed.

II. COMPOSITION AND WORKING PRINCIPLE OF CNC SAWING MACHINE

A typical CNC cutting equipment is as shown in Figure 1, mainly composed of a saw frame, guide posts, a master saw disc, a slave saw disc, a band saw, guiding devices, a cutting feed device, the workpiece to be sawed, a sawing work table, a table feed device, a clamping device, a tension device, a bed and a control system. The sawing principle of the equipment is as follows. The band saw blade winds on the master and slave saw discs though a guide device. The guiding device ensures that the band saw blade is parallel to the sawing section of the workpiece. The tensioning device tensions the band saw blade by regulating the distance between the master and slave saw discs. The main movement of the inverter motor drives the master saw disc to generate the linear motion of the band saw in the horizontal direction. The sawing feed movement is driven generally by the hydraulic pressure to result in the vertical linear motion. So they realize the cutting operation of the workpiece.[1-4]

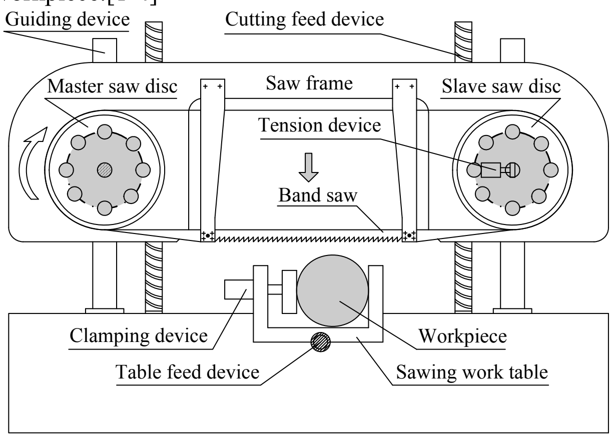

Fig.1 Composition of CNC cutting equipment

III. ADAPTIVE CONTROL SYSTEM WITH LOAD CHARACTERISTIC IDENTIFICATION

In the sawing process, because of changes in the material properties and the shapes of the cross section, the impact of cutting load is produced, which will affect the cutting precision and the surface quality. At the same time, under the different operating conditions, the load characteristic parameters are very different. The control mode of frequency control system is usually fixed, and can not be changed with the load. Therefore, it is difficult to get the ideal dynamic characteristics. That will result in the low working efficiency and the high energy consumption of the motor system.[5-9]

The adaptive frequency control method and system with the load characteristic identification detect the direct-current busbar voltage U_{DC}, the stator current i_a, i_b and the S_{abc} of the motor load system. The current, voltage and rotating speed under rotating coordinate can be obtained by the coordinate transformation, the voltage calculation and the adaptive PI identification. Those values will be the input values for identifying the load characteristic parameters of the motor system on real-time. According to the real-time load characteristics obtained by identification, they are compared with the optimal features under the setting rotation rate. The internal parameters in the DSP event manager are adjusted. The SVPWM wave forms are revised. Therefore the control property will be optimal. That improves the working efficiency and reduces the energy consumption of the motor system.[10-13]

In order to get the above goal, The adaptive frequency control method with the load characteristic identification measures the direct-current busbar voltage U_{DC}, the stator current i_a, i_b and the S_{abc} of the motor load system, transfers coordinate, calculates voltage, and identifies rotating speed by PI adaptation to obtain the input $U_{s\alpha}$, $U_{s\beta}$, $i_{s\alpha}$, $i_{s\beta}$ and ω_r of the characteristic parameter identification module for the motor load system. The module adopts the compound model of integrating neural networks with expert system. And the studying functions of neural networks sum up the new knowledge ceaselessly and enrich the knowledge base of expert system. The knowledge of expert system is used as the training samples of neural networks to accelerate the search rate of neural networks and to improve the real-time property of characteristic parameter identification. The adaptive identification of characteristic parameters obtains the parameters that reflect the actual load characteristics. The parameters are compared with the optimal parameters corresponding to the control parameter ω_{ref} for the control and correction reference of the SVPWM wave form.

In order to achieve the above purposes, the adaptive frequency conversion control system with load characteristic identification is given. The system has: the main AC-DC-AC circuit, the DSP control circuit, the RS485 communication circuit, the driving circuit, the analog and switch input/output circuit, the man-machine interface circuit and so on. The DSP control circuit detects the DC bus voltage, the three-phase AC current, the power module (IPM) temperature and other parameters. On the one hand through the transformation of the detected physical quantity, the voltage calculation and the adaptive PI identification of speed, the DSP event manager generates the SVPWM waveform, and identifies the load characteristics to modify the SVPWM waveform. Through the driving circuit, the power module is controlled to match the frequency control with the load characteristics and to improve the work efficiency. On the other hand, the system determines whether the physical quantity is abnormal. If abnormal, the blockade of the SVPWM waveform output is done to protect the variable frequency control system and the motor load system.

IV. CONTROL MODEL OF SAWING MACHINE

In order to give full play to the processing capacity of sawing machines, the cutting way of constant power is often used. Thus, while maintaining the high production

DOI 10.5013/IJSSST.a.17.26.12

ISSN: 1473-804x online, 1473-8031 print

efficiency, according to the material characteristics, the sawing force and speed can be optimized. The sawing control model of constant power is shown in Figure 2. In the Figure, aiming at the workpiece's material and shape size to be cut, the set-point power is calculated optimally to get the control values of the sawing speed and force. The controller 1 controls a converter's frequency, thus controls the main motor so as that the band wheels obtain the required cutting speed. Similarly, for the sawing force control, the controller 2 controls another converter's frequency, thus controls the feeding motor so as that the saw frame obtains the required sawing force. In the cutting process, the parameters for the material properties and cross-section shape are changed, so that the cutting speed and load also alter. By detecting the sawing speed and force, the feedback control is made.

According to the workpiece's material hardness, the level of the best constant sawing speeds in the horizontal and vertical feeding can be determined. The product of the vertical feeding speed and the workpiece's sawing width is the sawing force. So the key technology of realizing the constant cutting force is to give the feeding speed which alters with the change of the cutting width. The constant sawing force and varietal feeding rate can improve the sawing accuracy and efficiency, and prolong the service life of the machine tool and the saw blade. Therefore, the control model of the equipment's constant force is proposed, as shown in Figure 3. In the Figure, according to the cutting workpiece's material and shape and size, the control parameters are optimized to respectively give the control voltages of the main motor and the feeding motor. The controller 1 controls the converter's frequency, thus controls the main motor, to obtain the required sawing force for the band wheels. Similarly, for the feeding force control, the controller 2 controls the converter's frequency, and the feeding motor to obtain the required feeding force of the saw frame. In the cutting process, because the changes of the parameters such as the material properties and the cross-section shape, the sawing force and feeding force are changed. So the feedback control is done by the detecting of the force sensors.

Because the saw band is a flexible tool, the easy deformation in the sawing process affects the cutting surface's smoothness and precision. To this end, we propose the deviation control technology and system. Its control principle is shown in Figure 4. In the Figure, according to the workpiece's material and shape size, the tension position is set. The tension control is achieved by controlling the converter's frequency. The feedback control is made by the detection of the tensioning force. At the same time, in the cutting process, the positions in both ends of the saw band are detected, and compared with the set position value to control the feeding motor. It is finely tuned to form a closed loop control and improve the cutting precision.

V. AUTOMATION SYSTEM

The identification and adaptive frequency control system is as shown in Figure 5. The input signal and the detection feedback signal are compared. The difference is acted on the frequency conversion control module to control the motor running in accordance with the set of requirements. By detecting the feedback signal, the load characteristics of the motor system are identified, and the operating parameters of the variable frequency control module are adjusted to realize the optimal frequency conversion control of the motor speed control system.

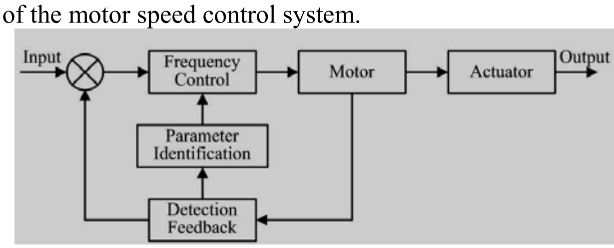

Fig.5 Block diagram of identification and adaptive frequency control system

The working process with load identification and adaptive frequency control is shown in Figure 6. The Hall sensors measure the DC bus voltage U_{DC} and the stator current i_a, i_b. The SVPWM module obtains S_{abc}. The voltage calculation module computes S_{abc} and U_{DC} to obtain $U_{s\alpha}$, $U_{s\beta}$. The i_a and i_b are transformed by the coordinate to get respectively $i_{s\alpha}$, $i_{s\beta}$, i_{sT}, i_{sM}. The $U_{s\alpha}$, $U_{s\beta}$, $i_{s\alpha}$, $i_{s\beta}$ are calculated through the current model and the voltage model to obtain $\hat{E}_r$ and E_r. The $\hat{E}_r$ and E_r are compared by the adaptive PI identification module to calculate ω_r. At the same time E_r *is* calculated by the rotor's magnetic declination to give θ_r. The $U_{s\alpha}$, $U_{s\beta}$, $i_{s\alpha}$, $i_{s\beta}$ and ω_r are used as the input parameters for the characteristic parameter identification module of the motor load system. The parameters of the motor load characteristics are obtained by the adaptive identification. The control parameters ω_{ref} and ω_r are compared. The difference passes through the PI speed control module to get the is T_{ref}, and is compared with i_{sT} to perform the PI torque control for getting the U_{sTref}. The control parameter ω_{ref} is transformed to give i_{sMref}, and compared with i_{sM} to perform the PI magnetic field control for getting U_{sMref}. U_{sTref} and U_{sMref} implement the coordinate transformation to obtain $U_{s\alpha ref}$ and $U_{s\beta ref}$ under the θ_e action for controlling the SVPWM waveform generation. The control parameter ω_{ref}, which is optimized by searching the parameter values, is compared with the motor load parameters obtained by the identification. The compared results are used as the control and correction reference for the SVPWM waveform. So the SVPWM waveform fits the load characteristics of the motor system to improve the efficiency of the system.

The software flow of the inverter control system integrated by identification and control is shown in Figure 7. First, U_{DC}, i_a, i_b and S_{abc} are detected. Second, the detected physical quantities are transformed in coordinate and calculated in voltage to obtain respectively $i_{s\alpha}$, $i_{s\beta}$, i_{sT}, i_{sM}, $U_{s\alpha}$, $U_{s\beta}$. Third, the control parameter ω_{ref} is transformed to get i_{sMref}, at the same time to get the optimal control parameter. Fourth, ω_r and ω_θ are respectively obtained by the adaptive PI identification and the rotor's magnetic angle calculation. Fifth, the control parameter ω_{ref} is compared with the actual speed ω_r obtained by identification, and i_{sTref} is gotten by the PI speed regulation. Sixth, the PI torque and magnetic field adjustment obtains U_{sTref} and U_{sMref}, and through coordinate transform $U_{s\alpha ref}$ and $U_{s\beta ref}$ are given to control the SVPWM waveform production. Seventh, the frequency control is required to match the load characteristics. The motor states identify the motor load characteristics, and are compared with the best control parameters to correct the SVPWM waveform output to the inverter, and then the frequency control is executed for the motor system.

The frequency control system structure integrated by identification and control is shown in Figure 8. It is composed of the main AC-DC-AC circuit, the DSP control circuit, the RS485 communication circuit, the driving circuit, the analog and digital input/output circuits, the man-machine interface circuit and so on. The frequency control system takes the DSP as the core, and detects the DC bus voltage, the three-phase alternating current, the power module (IPM) temperature and other parameters. On the one hand the detected physical quantities are transformed in coordinate, calculated in voltage and identified in the adaptive PI speed. The DSP event manager issues the SVPWM waveform. At the same time the SVPWM waveform is corrected through the load characteristic identification. The power module is controlled by the driving circuit to match the frequency control with the motor load characteristics and to improve the work efficiency. On the other hand, it is whether the detected physical values are abnormal. If abnormal, the SVPWM waveform output is blocked to protect the frequency control system and the motor load systems. The analog and digital input/output circuits link the inverter control system with the outside world. The RS485 communication circuit can transmit the control commands and parameters to the inverter control system, and output the running data of the frequency control system.

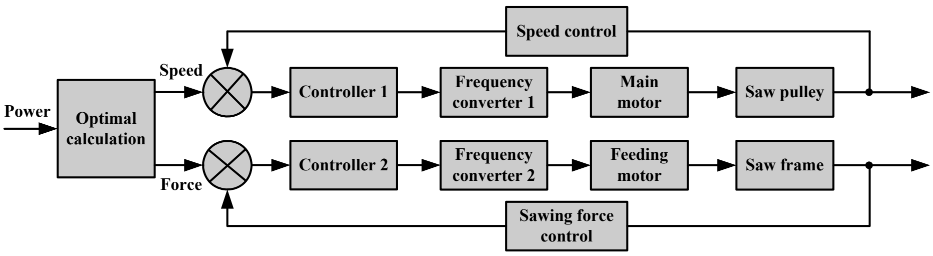

Fig.2 Sawing control model of constant power

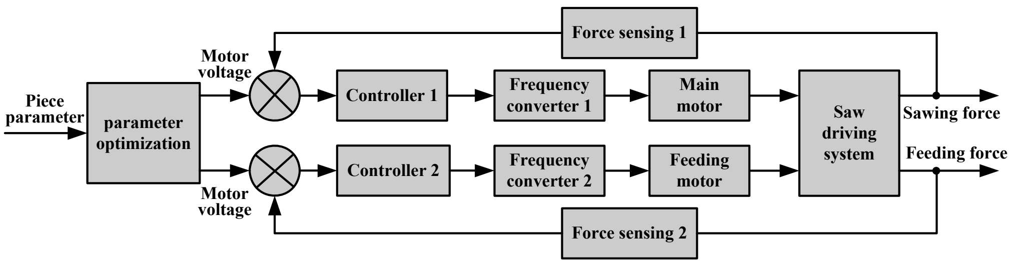

Fig.3 Control model of the equipment's constant force

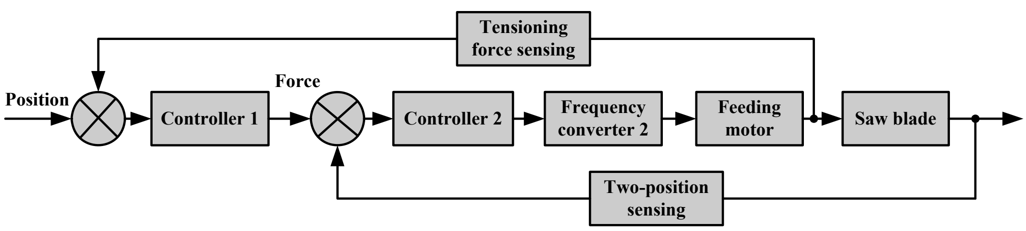

Fig.4 Deviation control system

DOI 10.5013/IJSSST.a.17.26.12 ISSN: 1473-804x online, 1473-8031 print

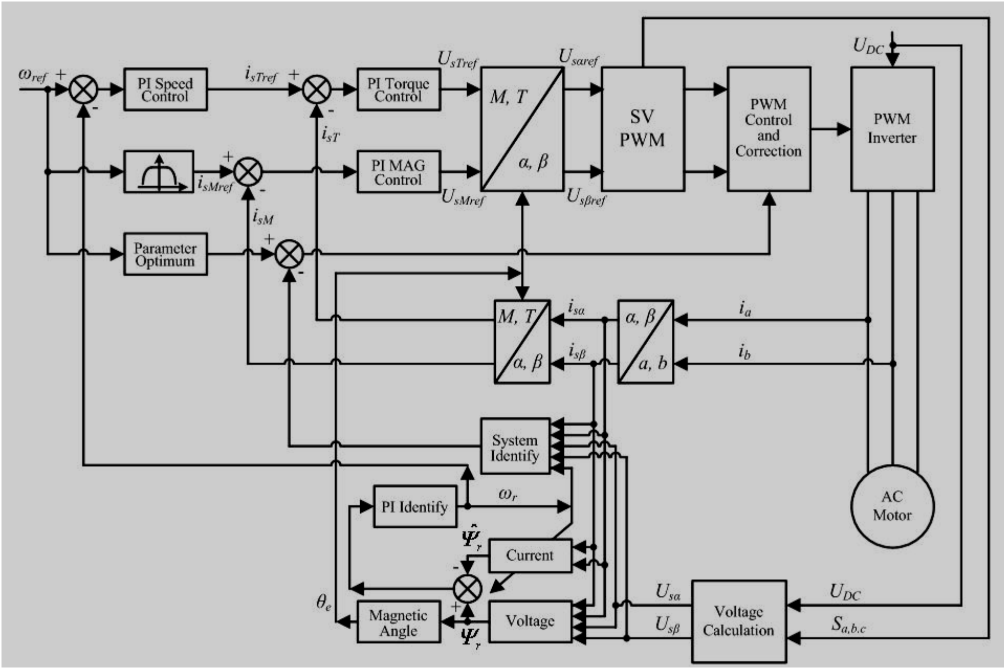

Fig.6 Working process with load identification and adaptive frequency control

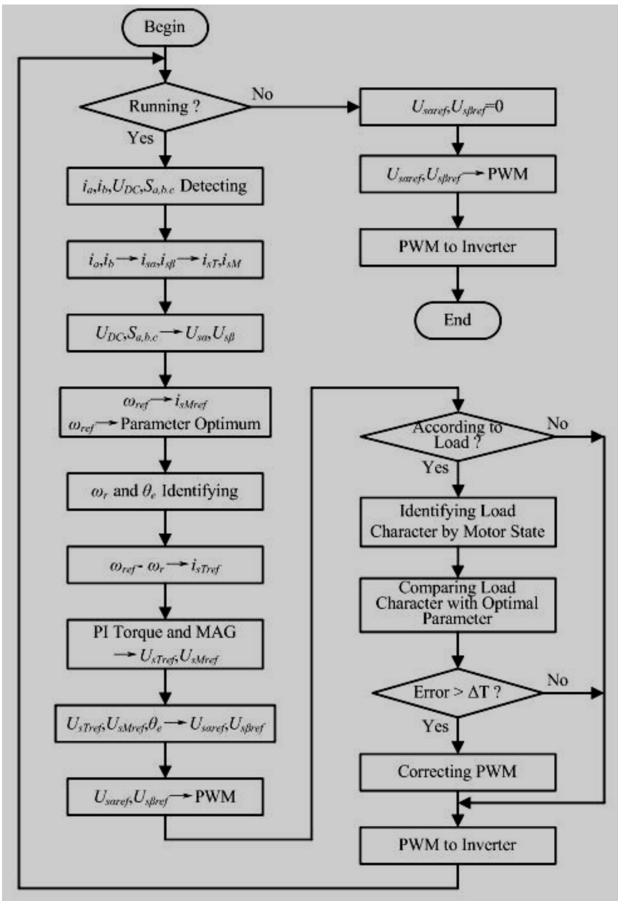

Fig.7 Software flow of the inverter control system

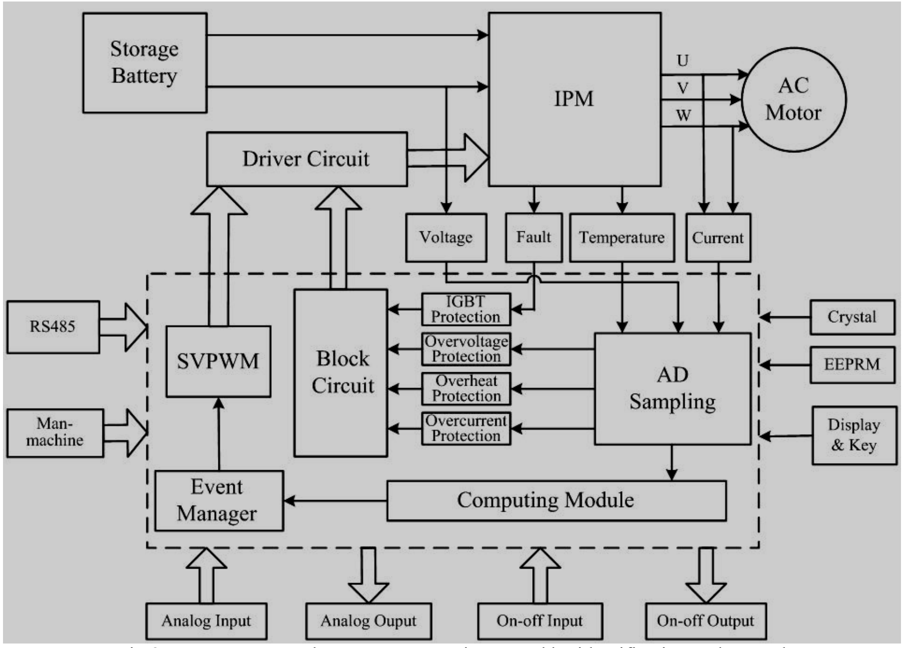

Fig.8 Frequency control system structure integrated by identification and control

VI. EXPERIMENTAL DATA AND WAVEFORM

For the above frequency control model and system with the adaptive load identification, the simulation analysis and experimental research have been implemented and used in the numerical control cutting equipment. First, the motor speed waveform is obtained in the given speed 120r/min and no load start, as shown in Figure 9(a). Then the speed is increased suddenly from 120r/min to 150r/min at 1s, and its speed variation waveform is shown in Figure 9(b). Finally, the load is added suddenly to 15Nm at 0.8s in the given speed 120r/min, and the speed change waveform is shown in Figure 9(c). In the figures, ω' is the simulation speed, and ω is the actual speed of the motor. It can be seen that (1) the simulation speed and the actual speed almost coincide in Figure (a). (2) the motor reaches steady at 0.6s, and the speed raises suddenly at 1s, and the simulation and actual values can respond immediately and reach soon to a given value at 1.4s, and the steady-state accuracy is better in Figure (b). (3) the load increases suddenly at 0.8s, and the speed decreases slightly, but it is soon recovered, and follows the given value sequentially in Figure (c). That indicates that the motor has better anti-interference performance to load, and can adaptively adjust to track the command value strictly by identifying the load.

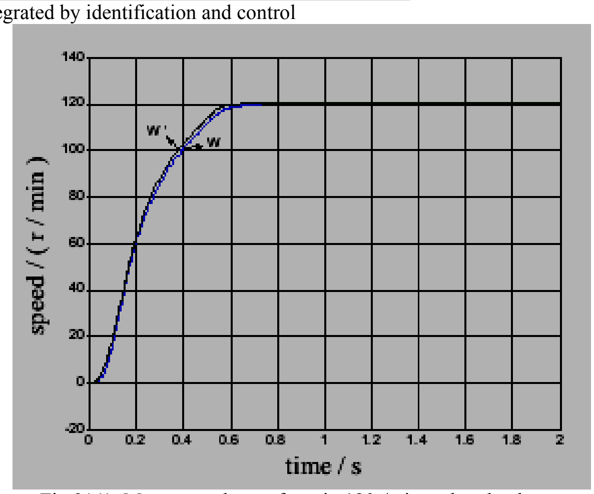

Fig.9(a)) Motor speed waveform in 120r/min and no load start

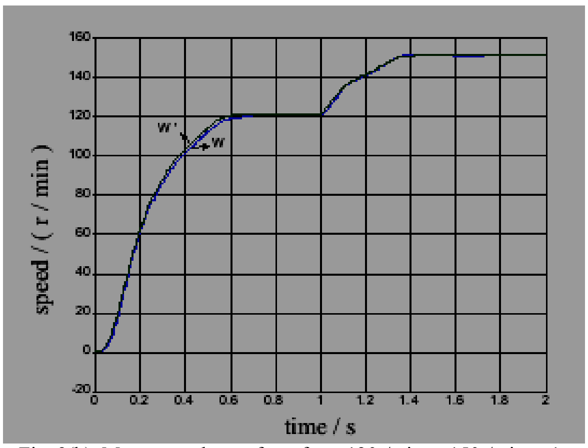

Fig. 9(b) Motor speed waveform from 120r/min to 150r/min at 1s

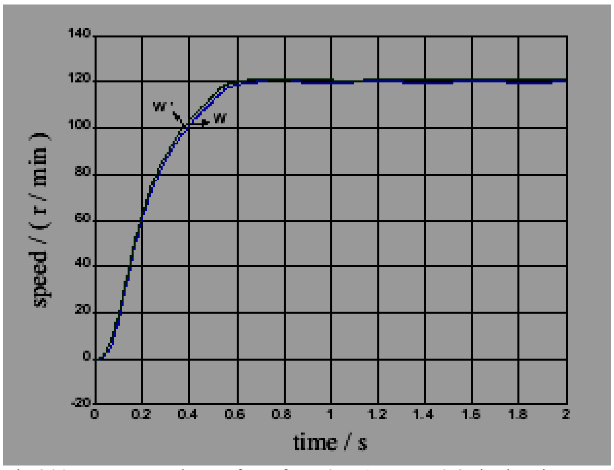

Fig.9(c) Motor speed waveform from 0 to 15Nm at 0.8s in the given speed 120r/min

VII. CNC SYSTEM BASED ON ERROR COMPENSATION

The CNC system based on the real-time error compensation and the auxiliary machinery intelligent control is shown in Figure 10. The electro-hydraulic servo system driven by the dual hydraulic cylinders synchronously is applied on the CNC cutting equipment. It makes the dynamic synchronous displacement error (the centimeter level in the mechanical synchronization system) ≤5 mm, the steady-state synchronous displacement error (the centimeter level in the mechanical synchronization system): ≤0.5mm. Through the CNC system based on error compensation, the cutting equipment achieves the cutting accuracy 0.1/100mm, the cutting line speed 120m/min, the cutting efficiency 80cm2/min, and the other excellent technical indicators in the maximum cutting diameter 2500mm.

VIII. CONCLUSION

We studied the adaptive variable frequency control method with load characteristics identification and designed the corresponding control system. The system can recognize the load characteristic parameters of the CNC sawing machine under the different conditions in operation, adjust the speed control system of variable frequency adaptively, and get the ideal dynamic characteristics, so as to improve the working efficiency of the motor system and reduce the energy consumption. In the control system, the numerical control module based on the real-time detection and the error compensation and the intelligent control of the auxiliary machinery is embedded. It improves the sawing precision. The simulations and experiments show that the system has strong adaptive capability, fast response speed, high accuracy and wide application in the cutting equipment.

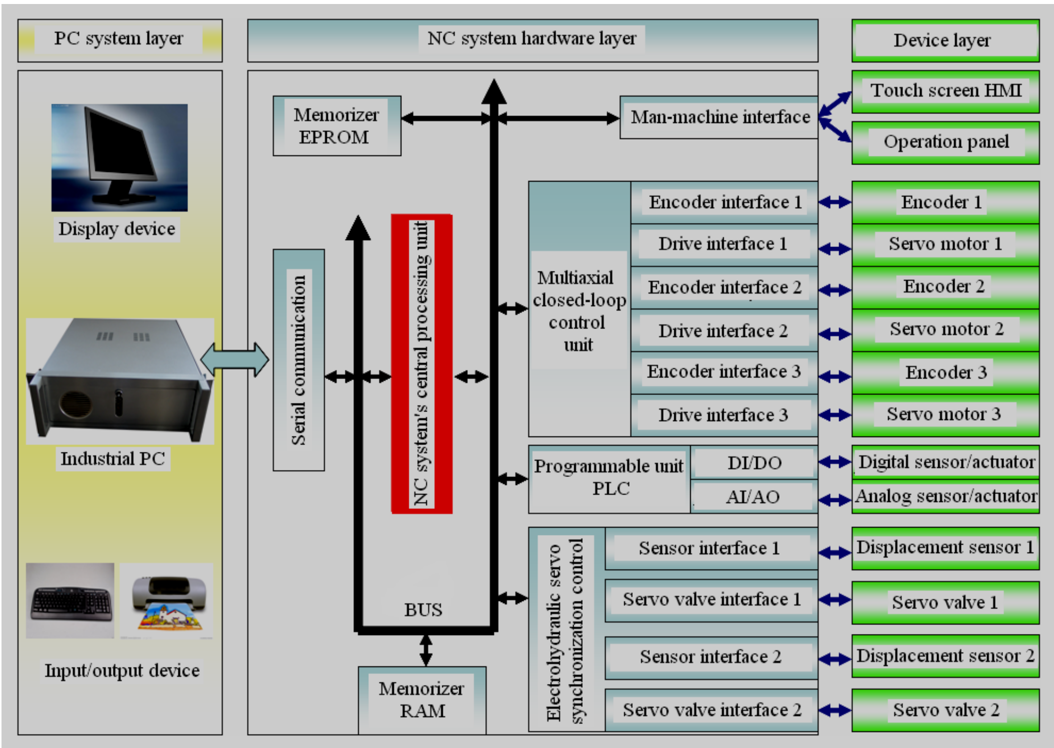

Fig.10 The CNC system based on the real-time error compensation

CONFLICT OF INTEREST

The authors confirm that this article content has no conflicts of interest.

ACKNOWLEDGMENT

The work has been supported by the Zhejiang provincial science and technology projects (2014C31098, 2011LM102) and the National small and medium enterprises' innovation fund projects.

REFERENCES

[1] CHEN Guo-jin, ZHU Miao-fen, NI Jing, CHEN Hui-peng, XU Ming, "Study on online detection and fault diagnosis of band saw equipment", *International Journal of Control and Automation*, v 7, n 8, p 157-172, 2014.

[2] ZHU Miao-fen, CHEN Guo-jin, CHEN Hui-peng, CHEN Li-ping, "Study on intelligent modeling and control for electric power steering system", *Journal of Applied Sciences*, v 13, n 13, p 2469-2473, 2013.

[3] ZHU Miao-fen, CHEN Guo-jin, GONG You-ping, LIU Ting-ting, CHEN Hui-peng, NI Jing, "Study on structural optimization design for band sawing machine", *Sensors and Transducers*, v 25, n SPEC.12, p 23-29, 2013.

[4] CHEN Guo-jin, ZHU Miao-fen, NI Jing, XU Ming, CHEN Hui-peng, "Study on dull-cylinder synchronous control technology and its application", *Journal of Applied Sciences*, v 13, n 18, p 3712-3717, 2013.

[5] CHEN Guo-jin, CHEN Hui-peng, CHEN Li-ping, "Research on multidisciplinary modeling and robust control for electric power steering system," *Advanced Materials Research*, Vol. 179-180, pp. 179-185, 2011.

[6] CHEN Guo-jin, DENG Kai-ping, GONG You-ping, "The Design and Simulation of Walking Hydraulic Transmission System of Loader HT25J," *Mechanical Engineer*, No. 6, pp. 46–49, 2012.

[7] CHEN Guo-jin, LIU Ting-ting, NI Jing, GONG You-ping and FENG Huo-qing, "Study on Control Characteristics of Driving and Lifting System for Logistics and Loading Machinery," *Applied Mechanics and Materials*, Vols. 268-270, pp 1517-1522, 2013.

[8] GONG You-ping, BIAN Xiang-juan and CHEN Guo-jin, "Excavator operator mechanism and hydraulic integration model construction and simulation based on modelica," *Applied Mechanics and Materials*, Vols. 130-134, pp 666-671, 2012.

[9] XU Ming, NI Jing, CHEN Guo-jin, "Research on the Broaching-load Testing System of Hydraulic Broaching Machine," *Advanced Materials Research*, Vols. 328-330, pp 1709-1712, 2011.

[10] ZHU Jie, CHEN Guo-jin, WANG Wan-qiang, "Applying FPGA on Frequency Convert System of SVPWM," *Mechanical & Electrical Engineering Magazine*, Vol. 22, No. 4, pp. 22–25, 2005.

[11] CHEN Guo-jin, YAO Zhai-rong, SUN Hong, "Realization of AC Motor Vector Control Based on DSP," *Mechanical & Electrical Engineering Magazine*, Vol. 21, No. 6, pp. 27–30, 2004.

[12] WANG Tao, CHEN Guo-jin, NI Jing, "Design and application of electric control system on pattern drawing machine," *Journal of Mechanical & Electrical Engineering*, Vol. 29, No. 4, pp. 413–416, 2012.

[13] LI Yong-ning, YANG Hua, CHEN Guo-jin, "Application of µC/OS-□ in digital welder control system," *Journal of Mechanical & Electrical Engineering*, Vol. 28, No. 7, pp. 827–830, 2011.